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A FIRE RISK ASSESSMENT METHODOLOGY FOR NAVAL VESSELS

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1. Introduction

The deployment of Naval vessels in combat requires a low vulnerability of the structure and systems to the effects of weapons strikes, the incorporation of appropriate damage control systems and a crew trained in damage control procedures. The crew training includes an intimate knowledge of the ship's hazard and protection features, to which the present work contributes. Fires may result from the effects of weapon strikes, combat training accidents (eg. fuel spills and helicopter recovery accidents) and as a result of human behaviour and procedures (eg. smoking and welding). The development of a fire risk assessment schedule for Naval ships as described in this work is based on a fire risk analysis for large commercial vessels reported by Grzeszkiewicz, Pride and Davis [1]. Emphasis in this assessment method is given to factors which govern severity of a fire rather than fire initiation.

Using the approach of Grzeszkiewicz et al [1], numerical values are assigned to hazard factors (positive) and to protection factors (negative) which are assumed to be additive. The scaling of these values is such that if adequate fire protection is available the risk factor obtained from a simple summation is close to zero or negative.

$$\text{RISK} = \text{HAZARD} + \text{PROTECTION} \qquad (1)$$

The present report describes the ranking scheme for hazard and protection factors, the method used for data collection, and the presentation of the reduced data set as a series of colour coded charts. Use of such fire risk data in ship design, damage control and fire modelling, is discussed.

2. Numerical Ranking of Fire Hazards and Protection

The objective in establishing scales for each component of hazard and protection factors was to provide a linearly additive scaling, which was indicative of the importance of each factor. The ranking scales established were based on the approach of Grzeszkiewicz et al [1], on the knowledge base of typical fires in Naval systems [2,3], and on discussions with Naval personnel on manning and operational requirements. The individual factors are discussed in detail below.

2.1 Hazard Factors.

The four hazard factors considered were the vital nature of the compartment to ship survival, the probability of accidental ignition, the fuel load and the fuel type.

2.1.1 Vital Space.

In a Naval vessel a compartment may be considered as either vital or non-vital to the principal ship objectives of fighting, moving or floating. The vital space factor prioritises the necessity to deal with a fire incident within a compartment, particularly when resources may need to be allocated between multiple incidents. In normal circumstances a compartment which is vital to float is more important than one necessary to fight or move, however this may depend on the tactical situation. The rankings we have adopted are:

Vital Space Value	Compartment
0	Not vital
1	Vital to Fight or Move
2	Vital to Float

In consultation with Naval personnel, each compartment was considered in terms of its functions, size and position in the ship. Those below the water line yet not water tight were considered to be part of the surrounding larger water tight compartment and were evaluated accordingly. No compartment above the weather deck was considered vital to float. All of the large machinery spaces were considered vital to float.

2.1.2 Relative Probability of Accidental Ignition.

Based on accidental fires in U.S. Naval ships the compartment types can be characterised with a probability of ignition related to compartment use [1]. Thus the probability of ignition in engine compartments and food preparation areas is higher than in storage areas. The factors

chosen are:

Accidental Ignition value	Occurrence	Typical Compartment
0	Remote	Store room
0.5	Occasional	Administration
1.0	Likely	Living/sleeping
1.5	Frequent	Engine spaces

2.1.3 Fuel Load

This factor reflects the hazard associated with the total fuel load in a compartment. The higher the factor the greater the likelihood that a fire, once started will reach "flash over" (all combustible materials in the compartment are ignited) and continue burning for a considerable time. Fuel load was defined as the total heat of combustion of materials in the compartment divided by the compartment floor area. Heats of combustion were obtained from the fire literature, tables of chemical and thermodynamic properties or calculated from the bond energies of chemical constituents. Extensive experimentation has shown that for fuel loads below 350 MJ/m^2 [4], flashover and complete combustion does not occur. Fuel loads below 180 MJ/m^2 are considered insufficient to maintain a fire. Compartments with values above 900 MJ/m^2 are considered capable of sustaining a fire for a considerable period of time. The hazard values for each compartment based on fuel load are determined from the following assignments.

Fuel Load Value	Fuel Load Range (MJ/m^2)	
0	0-180	unsustainable fire
1	180-230	
3	230-450	flash over marginal
5	450-680	flash over
7	680-900	
9	900-1500	long duration fire
10	1500-3000	
11	3000-6000	
12	6000-10000	
13	above 10000	

Fuel load values above 9 are considered to be equivalent to 9 for the purposes of ranking the hazard. These values, however, are included on the ship description to give an appreciation of the range of fuel loads within the ship. Knowledge of the fuel load and the ventilation conditions can be used to estimate the duration of a fire within the compartment.

2.1.4 Fuel Type

A fire will spread more rapidly in a compartment dominated by a material which is easily ignited (low flash point, eg. paper) than in a compartment which is dominated by a less easily ignitable material (eg. lubrication oil). This factor reflects the relative ease with which an ignition source can start a fire involving the combustibles within a compartment. The hazard values assigned are shown below.

Fuel Type Value	Ease of Ignition	Example
0	low	lubrication oil
1	medium	wood
2	high	paper
3	very high	petrol, gas

When assessing a compartment containing two or more fuel types the highest fuel type value should be assigned unless an insignificant quantity of that fuel is present.

2.2 Protection Factors.

Five protection factors were considered viz. fire sensing, occupancy, fire suppression system, barrier passive protection and distance to a repair base. These relate to the ability to detect, prevent the spread of, and respond to fires.

2.2.1 Sensing.

Fire sensing systems that respond to heat or smoke enable the detection of fires in otherwise unoccupied compartments. All types of sensors are assigned the same protection value.

Detection Value	Detection System
-0.5	infra red sensor, ionizing radiation sensor and heat sensor
0	none of the above

2.2.2 Compartment Occupancy.

An ignition source in an occupied compartment has a high probability of being detected before a fire becomes established. Rapid response using first-aid fire fighting measures during incubation and early stages of fire growth has a high likelihood of success, compared with the situation in unoccupied compartments. The assigned values are:

Occupancy Value	Occupancy
0	none
-1.0	occasional
-3.0	always

Occupancy depends on the ship's state of readiness, eg. cruising watch. Compartments occupied less than five minutes in the hour are considered unoccupied.

2.2.3 Fire Suppression System.

The installation of fixed fire fighting systems (eg halon, CO_2 etc.) that are triggered in the event of a compartment fire can give excellent fire protection. Systems with a lesser degree of suppression capability such as fixed water sprays, fire hoses and portable fire extinguishers are represented by less negative suppression factors. The values for each compartment are determined from the assignments below. For compartments with more than one suppression system the suppression value assigned to that compartment is the arithmetic sum of the suppression values of each system.

Suppression Value	Suppression System
-10	water flooding (non metal fires)
-7	installed halon flood
-4	installed CO_2 flood
-4	installed water spray
-2	hose and hydrant within 15m
-1	portable extinguisher within 15m
0	none of the above

2.2.4 Barrier Passive Protection.

The relative probability of fire spread from an adjacent compartment depends on the nature of the fire in that adjacent compartment and on the boundary between the two compartments. A fire wall is seen as providing passive fire protection and lesser barriers

provide less extensive protection. An external boundary reduces to zero the probablity of fire spread in that direction. Each compartment is considered as a box. The boundary material type for each of the six boundaries is classified into one of the following types of boundary and a value assigned.

Boundary value	Type
0	hull/external boundary
1	bulkhead (fire zone)
2	bulkhead (water tight)
3	steel decks
4	aluminium decks
5	steel partitions
6	aluminium partitions
7	other (eg. wood or permanent opening)

It is assumed that all vents and openings are shut. If they cannot be shut then the boundary in which the opening or vent exists is taken to have a boundary value of 7. With the exception of external boundaries, a value of one is subtracted from each boundary value if special fire retardant coatings have been used on that boundary. The values assigned to each boundary were added and factors for the degree of protection against spread of fire from an adjacent compartment are determined from the following assignments.

Value	Protection Against Fire Spread	Summed Boundary Value
-3	high	0-10
-2	moderate	11-20
-1	low	21-30
0		› 30

2.2.5 Distance to Repair Base.

The ability to rapidly deploy additional physical resources depends on the distance to those resources. In establishing distances it was necessary to determine which repair base would be used by the crew in a given area, not always the closest. For fighting a fire in a repair base itself, the next nearest repair base would be used and it is that distance which establishes the

protection factor. Based on distances of the compartment to the relevant repair base, protection values are assigned thus:

Repair Base Value	Access Distance (m)
0	› 30
-0.5	21-30
-1.0	11-20
-1.5	‹ 10

3. Analysis of Data

Two major sources were used for gathering data viz. ship detail drawings and a physical survey. The detailed drawing provided information on compartment boundaries and distances, as well as dimensions essential for use during the physical survey of the ship. In carrying out the physical survey measuring tapes, portable scales and a good eye are used to rapidly assess compartment contents, available fire fighting measures, barrier types etc. During the survey, the manning and vital nature of each compartment was established by discussion with Naval personnel. A data sheet shown in Fig. 1, was designed to record relevant information. One data sheet was used for each compartment.

The most difficult aspect of the fire risk assessment was the determination of fuel loads. For many solids and liquids data is available on heats of combustion [4,5]. If such data were not available, heats of combustion were estimated from bond energy data. In some compartments considerable detail was available on the contents, whilst for others information was limited. For example in a magazine the number of rounds, the quantity and type of explosive, propellant and other combustible components can be used to accurately determine the fuel load. However in berthing spaces only average estimates on bedding and personal items could be used.

The values for each hazard and protection factor were recorded on the data sheet for each compartment (Fig. 1). Once all values had been assigned, these were summed to give overall values of hazard and protection and, using equation (1), a value of risk. For each of hazard, protection and risk a colour coded chart of the ship is constructed. The corresponding numerical values of hazard, protection and risk are included for each compartment on these

charts. In addition, on the hazard chart the fuel load factors have been included for each compartment. The colour code is arranged with the less desirable condition indicated as red and the more desirable condition indicated as blue. Fig 2 shows risk charts of several decks of a hypothetical frigate class ship. For a single deck from this ship, the hazard, protection and risk charts are shown in Fig. 3.

4. Discussion

The colour coded charts clearly have value as a tool in damage control where rapid visual inspection can indicate the likely progress of a fire. Visual inspection of the fire risk chart assumes all protection measures are operable. However, if fire extinguishers are depleted or a fire main has burst in a particular area, then the hazard chart may depict the likely severity of a fire incident in that area with greater accuracy than the risk chart. The incorporation of the charts into a computer software model could produce a tool that would allow the rapid assessment of the effects of removal or augmentation of fire protection measures. This in turn, could be utilised in ship design or to aid decision - making during a fire incident. This fire risk assessment method has enabled a systematic documentation of fire hazards, and realistic analysis of the degree to which compartment contents and fixtures contribute to the magnitude of the fire load.

The numerical values assigned to hazard and protection factors can be debated. At present the hazard is dominated by fuel load and this biases the analysis towards severity of a fire incident rather than probability of accidental ignition. This is appropriate for a Naval vessel which is being assessed for a combat role as opposed to the considerations of a merchant ship which may need to be assessed on an insurance risk basis.

The fuel load factor, shown on the hazard charts, gives an indication of the relative severity of fires in different compartments. Calculations based on fuel load per unit area, room geometry and opening details can be used to estimate the intensity and duration of fires- these details being retained on the individual compartment data sheets. Within the accuracy of fire calculations and the generally limited range of ship compartment geometries (dimension ratios), a simple factor can generally be used to convert fuel load per unit area of floor to fuel load per unit total surface area. Ship board fires are almost always ventilation dominated. However, ventilation conditions for use in fire calculations involve a knowledge of the flow rate of forced ventilation and of the type of incident (eg. ship hull perforation by weapon) which are variable quantities during fire incidents. As a general result, the fire duration may be considered to be proportional to the fuel load factor, and fire intensity proportional to the ventilation.

5. Conclusion

A fire risk assessment methodology has been described which gives a numerical ranking of the hazard and fire protection factors and an estimate of fire risk by combining these factors. The ranking system weights the likely severity of a fire and as such is relevant to the deployment of combat vessels. The data can be presented in an easily understood set of charts which are shown to be of value in ship design, damage control and training. The data collected by the above analysis technique has been used to configure the "FIREMAID" simulation package, described in an accompanying paper [6], to specific naval ships.

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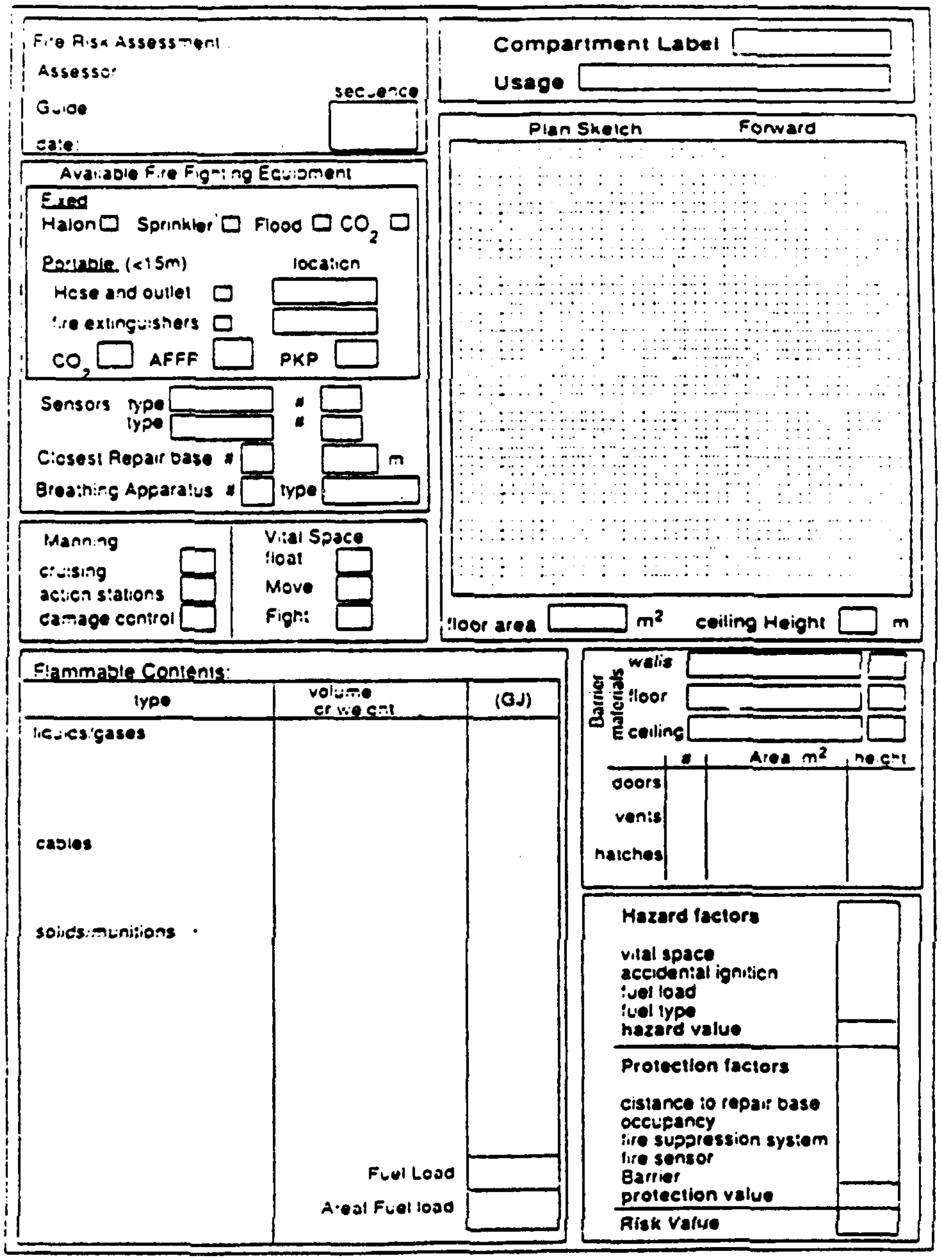
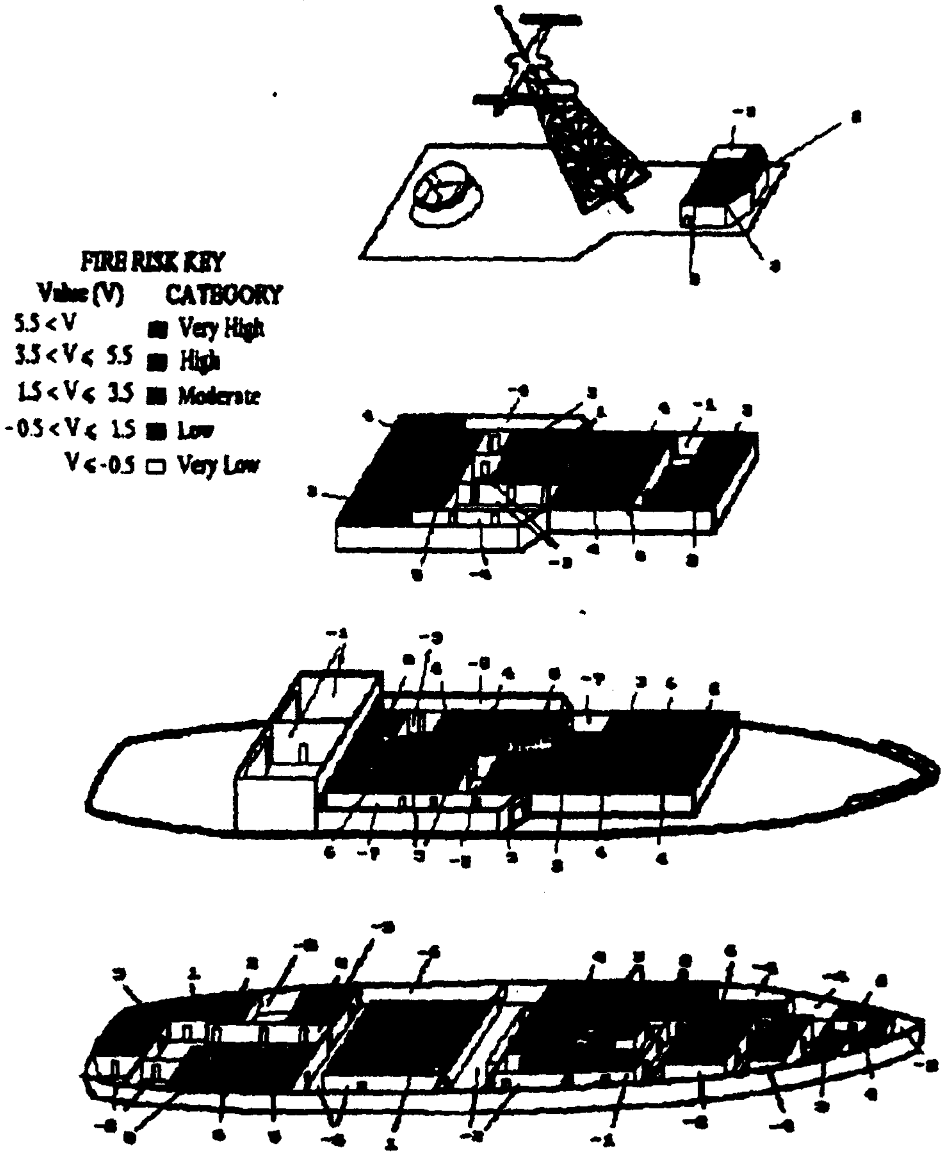
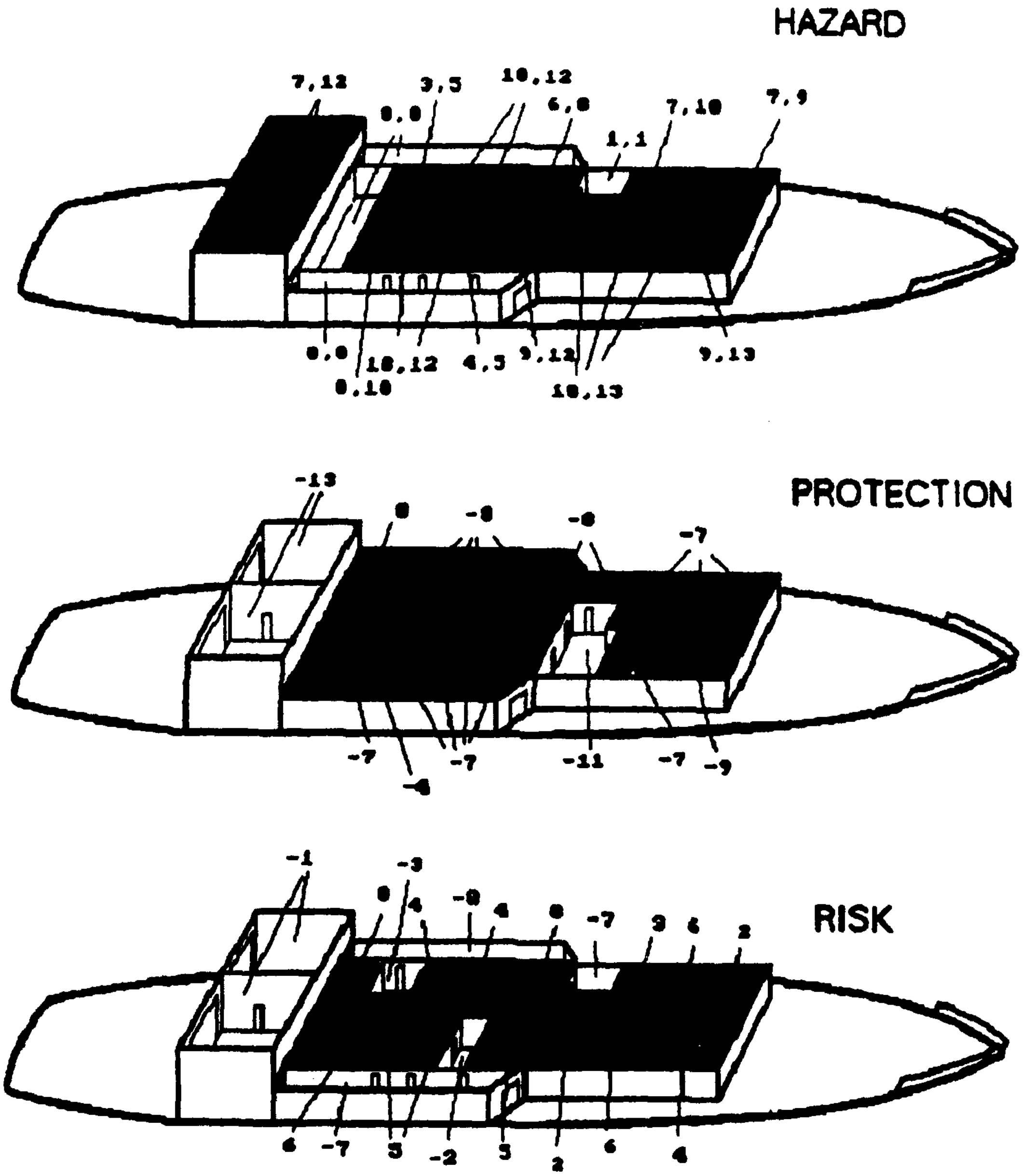


1. Data sheet designed for the collection of compartment data and for conversion to numerical rankings of hazard, protection and risk.



2. Several decks of a hypothetical surface combatant showing the presentation of risk values numerically and with the use of colour coding.



3. Presentation of hazard, protection and risk values for 01 deck of the surface combatant shown in Fig. 2. On the hazard chart the first number is the fuel load factor and the second number is the hazard value.